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An Assessment of the Technical Literature on Emergency Egress from Buildings

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Center for Building Technology
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Washington, D.C. 20234

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Prepared for the Center for Fire Research, in support of:
OSHA-NBS Emergency Escape Requirements Project
Sponsored by:
Occupational Safety and Health Administration
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and

HEW-NBS Fire/Life Safety Program
Sponsored by:
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ACKNOWLEDGEMENTS

The NBS-OSHA Emergency Escape Requirements Project is directed at identifying the data base, assessing the capabilities of selected elements, and providing the technical basis of hazard assessment as each relates to emergency escape from the workplace. The HEW-NBS Life/Fire Safety Program involves a series of interrelated projects in the areas of decision analysis, fire and smoke detection, smoke movement and control, automatic extinguishment, and the behavior of institutionalized populations in fire situations. This project, an important part of the overall Emergency Escape Requirements Project, was conducted within the Architectural Research Section of the Center for Building Technology, IAT, National Bureau of Standards.

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EXECUTIVE SUMMARY

A technical assessment was made of the literature on research, and the data base related to current emergency egress regulations promulgated by the Occupational Safety and Health Administration (OSHA). The purposes of this assessment were to ascertain the extent to which these regulations were based upon empirical research, and to determine the adequacy of available research findings from which OSHA emergency egress regulations may be developed.

Three distinct areas of research on emergency egress were identified: (1) research on the carrying capacity of exitways, (2) research on signage, lighting, and visibility through smoke, and (3) research on occupant responses to, and experiences in building fire emergencies.

Only research on the carrying capacity of exitways appears to have had direct impact on current OSHA regulations, which are based largely on empirical findings reported in 1935. These findings are currently under challenge by J.L. Pauls, of the National Research Council of Canada. Pauls found that, during fire drills in high-rise office buildings, the flow capacities and discharge rates of stairs and exit doors were significantly lower than statistics reported earlier, and assumed by current regulatory authorities. Aside from the usual discrepencies among available research data, however, the scientific merits of this data base remains an open question. Moreover, no single approach to the study of carrying capacity seems sufficiently comprehensive to account for the egress problem taken as a whole. Where various methodological shortcomings of the original carrying capacity research are taken into account, this portion of the egress data base may be appropriately applied to design problems in which direct, immediate, and well-staged exiting behavior can be anticipated.

Much of the available data on egress signage, lighting, and visibility through smoke has appeared since the adoption of standards by OSHA, and consequently this area of research has had minimal impact on OSHA egress regulations. Although most of this research has involved well controlled laboratory experimentation, this portion of the data base suffers problems which arise whenever we try to generalize from controlled laboratory experiments to actual fire environments and experiences.

Recent post-incident studies of occupants responses in real fire situations have appeared after the adoption of emergency egress standards by OSHA. At present, this portion of the literature seems the most limited in its applicability to design or regulation. This is due to the general failure of investigators to consider the role of building layout and exit arrangement in their research. However, the importance of these studies lies in their delineation of emergency egress scenarios, their identification of response patterns, and their exposure of frequencies with which such patterns have actually occurred during building fires. Explication of these issues is believed essential to any future program of regulatory development in the emergency egress area.

On the basis of the technical literature assessment, the following categories of research are recommended for intensive investigation:

(1) Research on access to exitways;

(2) Resolution of the discrepencies between findings by Pauls and other investigators of the carrying capacity of exitways;

(3) Continued research on egress signage, lighting, and visibility through smoke (e.g., the work at the Center for Building Technology, IAT, National Bureau of Standards, which is currently under the sponsorship of OSHA); and

(4) Definitive identification and description of emergency egress scenarios and response patterns.

Specific recommendations concerning research strategy and technique are also offered.

1. INTRODUCTION

1.1 Purpose

The overall purpose of the investigation was to carry out an in-depth literature study, leading to an assessment of the data base underlying current standards for emergency egress facilities in occupancies regulated by the Occupational Safety and Health Administration (OSHA).

The present report represents a critical assessment of the technical literature pertaining to emergency egress. As only small portions of this literature have been specifically applied within the regulatory process, the review should not be construed as an evaluation of current regulatory policy.

1.2 Significance, and Specific Objectives of the Study

1.2.1 Significance

The method of generating standards and including them in legislation or regulation is complex, subject to wide variation, and at times quite controversial. A major element in the development of standards, and in the adoption and implementation of building regulations, lies in the breadth and depth of research data available to support the reasonableness of the standards. It is not always feasible for regulatory agencies to support design standards through reference to research. The inability to argue the efficacy of regulatory standards on the basis of relatively unbiased technical support has, moreover, added to the difficulty inherent in enforcement. It is believed that this problem can be mitigated through the accumulation of a well-founded base of technical literature.

This report provides an assessment of the supporting technical base for emergency egress regulation provisions in current building codes. This assessment is intended to aid regulatory officials in judging the credibility of currently promulgated codes, and to guide development of research programs leading to any needed changes in standards that would be more effective in actual conditions.

1.2.2 Specific Objectives

The following objectives guided the conduct of the study:

(a) to identify the technical literature relevant to emergency egress from buildings housing work environments;

(b) to evaluate the validity and usefulness of the available technical research as a supportive basis for building regulation;

(c) to identify key knowledge gaps concerning emergency escape, and to recommend useful avenues for futher research.

1.3 Scope

The specific focus of the technical literature study was on emergency escape arrangements for individual workers or groups of workers. Investigations of egress width, flow rates, travel distance, and the physiological and psychological capabilities of humans under deteriorated environmental conditions were taken into account.

1.4 General Problem and Overview

1.4.1 The Occupational Safety and Health Act: Purposes and Mechanisms

The fundamental intent of the Occupational Safety and Health Act of 1970 (1)* is to insure safe and healthful working conditions for men and women, through the development, promulgation, and enforcement of reasonable standards. The Act specifically directs the Secretary of Labor to "promulgate as an occupational safety or health standard any national consensus standard, and any established Federal Standard unless he determines that the promulgation of such a standard would not result in improved safety or health for specifically designated employees" (2).

Toward the achievement of these ends, the Act specifically provides for the conduct of research relating to occupational safety and health. This includes the study of toxic and harmful environmental agents, and of pertinent psychological factors, for the purpose of establishing bases for the adoption and enforcement of regulations.

1.4.2 State-of-the-art of Egress Research

Throughout this century, investigators seeking to gather data relevant to the problem of emergency exiting from buildings have relied upon conventional research techniques. For example, the early NFPA and NBS studies of crowd-flow in various occupancies utilized the basic technique of counting numbers of persons passing by a fixed point in space during an arbitrarily defined time unit. The primary intention of the early investigators was to measure the "carrying capacity" of egress route components (corridors, doors, stairs) of various dimensions and designs. Occupants were studied during periods of normal building usage, while they were clearly in no danger. However, research findings have been assumed to generalize to cases of emergency egress, for the purpose of developing or evaluating life safety standards.

The same general approach to egress research continued into the 1950's most notably by K. Togawa (1955) in Japan (who developed elaborate mathematical models of building egress from his data). Even by the 1970's, studies of egress carrying capacity, based on the traditional assumptions, were in progress. Examples of the most recent work include research by I. Peschl (1971), J.J. Fruin (1971), and S.J. Melinek and S. Booth (1975).

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*Footnotes appear at the end of the paper.

It is important to note, however, that not all investigators concerned with the measurement of carrying capacities found results compatible with current building regulations. J.L. Pauls (1975), for example, demonstrated that the true carrying capacity of stairways may be substantially smaller than that generally assumed by code writing bodies. Observing high-rise building occupants on stairs during fire drills, Pauls noticed a swaying motion and a staggered distribution of persons on the stair treads. Such evidence called into question the traditional practice of assessing stair adequacy on the basis of the 22-inch linear file, and the related assumption that on stairs, persons can be expected to walk two abreast. Through the same series of drill investigations, moreover, Pauls suggested that total evacuation time for tall buildings may be erroneously estimated if one merely employs mathematical models of the type developed earlier by Togawa. According to Pauls, egress management and staging may be as important as the provisions of adequately sized corridors, doors, and stairs for the evacuation of critical areas, although the former are not presently specified in building codes and standards.

A second category of empirical research includes work in issues directly relating to emergency egress, though outside the context of buildings. Experiments on egress route signage and emergency lighting have been conducted by the U.S. Navy. These studies focused on the problem of fires and other emergencies on board aircraft carriers and other large vessels. Additional research has been under way at the Federal Aviation Administration's Office of Aviation Medicine. This experimental work has emphasized the study of exit sign and marker visibility through smoke, and the effects of brightness and contrast on sign perception.

Finally, a small number of researchers have departed substantially from the experimental and quasi-experimental approaches discussed above and have relied instead upon social-survey techniques. Their principal concern has been to gather useful data on occupants' experiences during actual fires, and to cover not just egress movement, but a more general and broader range of behaviors. The first comprehensive investigation of this type was conducted in 1972 by P.G. Wood in the United Kingdom, who interviewed victims from more than 1,000 incidents (mostly residential fires). Modeling his study after Wood's, J.L. Bryan (1976) also interviewed victims of residential fires, in the Washington, D.C., vicinity. A major objective of both researchers was the reconstruction of actual behavioral sequences, reported to have transpired during fires. Along similar lines, the National Bureau of Standards has undertaken a sociological investigation of fires in several nursing homes (G.M. Haber, in progress). Emphasis is focused on understanding participants' feelings about, and emotional responses toward, their fire experiences.

In summary, several general observations on the state-of-the-art of egress research can be made:

(a) Three distinct areas of research on fire egress have been undertaken. These are:

(1) studies of carrying capacities within protected exitways;

(2) studies of signage, lighting and visibility under fire conditions; and fire emergencies.

(3) studies of occupant responses to, and experiences in, fire emergencies.

(b) Investigations which yielded numerical data on exiting capacity were conducted either under ideal laboratory-like conditions, or in real buildings during periods of normal occupancy. In such studies, subjects were not under any threat of injury or death, and didn't believe they were. Findings from such investigations, have often been, however, assumed to generalize to egress during real emergencies.

(c) Most investigations of egress capacity report similar trends, although interpretations appear to vary somewhat widely.

(d) Investigations of egress facility capacity emphasized the "safe end" of the evacuation system (i.e., fire resistive corridor and fire stair design), while ignoring the "threatened end" (spaces on buildings' floors where life-threatened stimuli are likely to be first experienced, and where information is likely to be most ambiguous).

(e) Social survey research in which fire victims were interviewed has not emphasized issues peculiar to the design of exits. Rather, the reconstruction of social and behavioral action systems has been stressed.

(f) In general, empirical research on emergency egress has considered various narrowly defined aspects of the problem. For instance, those investigators concerned with the carrying capacity of stairs or doorways usually ignored psycho-social factors. Similarly, those who questioned victims about their response patterns generally failed to correlate these findings with meaningful measures of the threat-laden environment.

1.4.3 Emergency Egress Scenarios

A variety of diverse emergency egress behavior patterns may occur in such large-scale work environments as department stores, plants, or multi-story office buildings. In many instances, such facilities consist of complex arrangements of functional spaces and circulation ways, and are designed with varying degrees of fire or smoke retarding compartmentation. In other cases, entire floors may be open, and may be separated from each other by fire-resistive construction. As a result of such spatial organization, fire products often never spread beyond resistive barriers (where these are provided), before they are extinguished. It is rare that an entire facility would become engulfed by flames or smoke. Even where this might occur however (as in the tragic office tower fires in Brazil, or in the recent Beverly Hills nightclub disaster in Kentucky), environmental conditions will deteriorate progressively, and some spaces within the building will remain minimally affected longer than will others.

Empirical research on human behavior in fires has only begun to explicate the relationship between occupants' egress patterns and specific degrees of exposure to a life-threat. For the purposes of our discussion, however, it seems reasonable and appropriate to assume that a person's actions in time of fire will depend upon the quality of the emergency experience.

For example, occupants located far from the involved zone may take no emergency actions at all, if they receive no information indicating the existence of danger, or if they perceive their situation to be safe. Other individuals, though not actually in the hazardous zone, may have received specific information about the fire's location and intensity, as well as instructions on what to do or where to go. Many of these persons are likely to proceed directly from their work stations to protected exit ways, refuges, or to the outdoors. Others may be less immediate in their escape actions, and may gather belongings, assist or alert other occupants, etc.

There may be other situations, however, in which emergency egress behavior is even less likely to be deliberate, immediate, or adaptive. Persons in the building, remote from the involved areas, may receive ambiguous information about the status of the fire and of their own relative safety. Similarly, individuals may be misinformed as to the facts about fire and smoke migration, or as to the life-protecting capabilities of fire-resistive building construction. Such factors may contribute to an inaccurate perception of danger, or to a false sense of security. These may in turn delay emergency evacuation activities, or evoke non-adaptive or misguided emergency behavioral patterns.

Finally, a person may respond even to the most unambiguous life threat on the basis of incorrect information or training, and habit. A case in point is the direct, unimpeded movement of persons from work stations to elevators (the egress route with which they are probably most familiar), rather than to the specifically designated and protected fire stairs.

1.4.4 Emergency Egress Response: Generic Patterns, and their Support in the Technical Literature

The foregoing scenarios illustrate several factors which we may presume influence the quality of an individual's emergency egress response. These factors include: (a) accuracy of threat perception; (b) quality of cues and quantity of information about the life-threatening environment; (c) familiarity with building layout; (d) familiarity with emergency procedures and egress routes; (e) immediacy and purposefulness of the egress response; and (f) location within the building. On the basis of these factors, we may derive a set of generic emergency egress responses. These include:

(1) direct egress behavior on a building floor, along an appropriate route;

(2) direct egress behavior in a fire stair or other protected exitway;

(3) direct egress behavior along an inappropriate route (e.g., path leading toward an elevator rather than a stair);

(4) indecisive egress behavior (e.g., non-adaptive or indiscriminate route-shifting during evacuation);

(5) indecisive pre-egress behavior (e.g., investigation);

(6) delayed egress behavior (due to e.g., warning or assisting others, or collecting personal articles prior to actual egress movement);

(7) re-entry behavior (after having left the threatened zone).

Emergency egress behaviors and scenarios of the kind described above are quite likely to occur during the various stages of a building fires in an occupational occupancy. Important questions, then, concern not only the quality of the emergency egress data base, but also the degree to which empirical research has specifically explicated each generic response category. We noted earlier that three distinct foci were found in the empirical literature on egress. But to what extent has this expansive data base actually addressed the unique problems peculiar to various emergency egress scenarios?

1.4.5 Problem Summary

Briefly stated, then, the problem in this report was to determine the extend to which the available technical literature on emergency egress is capable of supporting design standards promulgated by OSHA.

2. METHOD OF STUDY

2.1 Approach

This report's technical literature evaluation was organized about two distinct phase:

(a) a "descriptive" phase, and

(b) a "critical" phase.

In the descriptive phase, items were abstracted and the authors' hypotheses, findings, inferences and recommendations were taken at face value. Our results are documented in Chapter 3. The critical phase provided an opportunity to delve analytically into each item. Here, the usefulness of the research to the egress state-of-art, and to the concerns of OSHA, was assessed, as was the validity of research findings, and the appropriateness of research methods. Moreover, an attempt was made to evaluate specific inferences drawn by the investigators. This assessment is detailed in Chapter 4.

Finally, principal content areas within the literature were assessed to determine their contribution to the explication of specific emergency egress scenarios. Appropriate recommendations concerning the applicability of various segments of the technical literature are offered in Chapter 5.

2.2 Procedure

2.2.1 The Literature Search

An effort was made to cover a wide spectrum of materials dealing with the problem of emergency egress from buildings. After a cursory inventory, it was decided not to limit the review to materials specifically involving OSHA-regulated facility types. The decision to approach the egress literature more broadly was based on the considerations that:

(a) the egress literature itself is not neatly partitioned in terms of building types or hazard classifications, and

(b) the Life Safety Code, from which OSHA's exiting regulations were adopted, carried implications for virtually all building types in common use. Moreover, the broader search strategy permitted the inclusion of salient research lying outside the general building literature. Studies conducted by the U. S. Navy, and by the Federal Aviation Administration are chief examples.

Literature identified as appropriate to the objectives of the study generally clustered into four distinct categories, including:

(a) materials which <u>specifically report empirical data</u> on exiting behavior, carrying capacities of pedestrian ways, or the attitudes and beliefs of fire victims;

(b) background or supporting materials from cognate areas, particularly the behavioral sciences, which assist in the interpretation and evaluation of the available empirical evidence;

(c) materials which suggest or illustrate the shortcomings or assets of current regulations, either by reference to case studies or design solutions, and not on the basis of empirical data;

(d) materials which illuminate the process through which research findings are incorporated into building regulations.

2.2.2 Criteria for Evaluation

The critical phase of the technical literature review was accomplished by evaluating each item against various issues:

The relevance of findings or conclusions to the egress state-of-art, and to the concerns of OSHA, was first considered. Of principal interest was whether the material had potential value in improving our understanding of the emergency egress problem. In addition, the degree to which authors' conclusions were cast in language compatible with the writing of regulatory statements, was assessed.

Increasingly, research on emergency egress has raised questions concerning the reasonableness of assumptions which underlie life-safety regulations. Of special interest, then was the identification of assumptions implicit in examples of such research. This process focused upon investigators' conceptualization of research problems, wherein assumptions about the relevance of variables, or about systemic interrelationships among certain factors, frequently operate. It was often found that such assumptions were either ignored (or at least omitted from authors' reports), or else inadequately considered in the development of research strategies.

When commenting upon their data, researchers often drew inferences concerning safety policy, building design, or regulations. In many cases, however, authors attempted to generalize their findings to real-world contexts not adequately simulated by their investigations. Examples include inferences about corridor width and staircase adequacy during fire emergencies, drawn solely on the basis of data gathered during periods of normal occupancy.

The research design itself was also evaluated, in order to determine the validity of findings, and the extent to which authors' conclusions were justified.

Other aspects of the critical evaluation involved tracing the degree of corroboration among investigators, and comparing research findings with current design practice.

Finally, an attempt was made to assess the value added by specific investigations to the emergency egress literature. Occasionally, for example, items were found which provided the only known data base for an issue. A

case in point is the work of Johnson and Jones (1976), who provided data on the manueverability of stretchers through corridors, around corners, and through elevator doors. In other examples, investigators employed new methods of gathering data. Pauls, for instance, replaced earlier methods of head-counting during normal occupancy periods with video recording and motion picture filming during evacuation drills. The tapes and films could then be replayed later in the laboratory, as many times as necessary. Still others contributed theoretical schemes useful in conceptualizing the egress problem (e.g., Henderson, and Breaux, et al.).

3. THE EMERGENCY EGRESS TECHNICAL LITERATURE

3.1 Historical Development of Emergency Egress Literature

In addition to abstracting materials during the "descriptive" phase of the review, the principal sources cited by investigators were recorded. This permitted tracing the history of research methods and approaches to the egress problem. Figure 1 illustrates the results of this exercise.

Several key points are suggested by the geneological analysis. The first is the lack of empirical research input into egress code development after 1935, when the NBS conducted its studies on the carrying capacity of exiting facilities. NPFA-101, and consequently OSHA's exiting standards, have not taken advantage of investigations conducted any more recently.

The geneological analysis also demonstrates that by the 1970's, two distinct schools of egress research had emerged:

(a) the "carrying capacity" school represents those investigators who emphasize the importance of providing properly designed exit facilities in adequate numbers. Their research has generally involved the measurement of flow rates through various pedestrian ways in buildings.

(b) the "human response" school recognizes that the provision of properly designed and located exiting facilities is a necessary, but not sufficient, condition for the assurance of life-safety from fire. Studies by these investigators have stressed the need to model human spatial movement patterns and decision-making behavior, in an emergency situation which often provides highly ambiguous perceptual cues.

The dichotomy seems amply supported by our historical analysis, which also revealed a critical lack of cross-fertilization between the two schools.

Our analysis further suggested that Pauls' work may have bridged across the two schools through research concerned with both carrying capacity and human response. Pauls, as was mentioned earlier, measured flow capacities and evacuation time during fire drills in tall buildings. Moreover, his interpretation of findings reflected a concern to relate physical design parameters with the psycho-social phenomena believed to operate during building emergencies. Melinek and Booth cited Pauls' work for its value in carrying capacity measurement; Canter, et al., valued its implications for understanding behavioral processes (human response) during building fires.

3.2 Evaluation of the Empirical Research Base: Investigations of "Carrying Capacity", Based on Physical-Science Models

As suggested elsewhere above, it may be useful to think of the empirical research on exit carrying capacity as representing two viewpoints. These are:

(a) The acceptance of a physical-science model (e.g., the "hydraulic" model) as an explanation of human movement in buildings. Such acceptance may be either implicit or explicit.

(b) A rejection of the physical model as sufficient (either by itself, or in its traditional form) for the conceptualization of egress behavior.

The former view shall be considered first, by presenting in detail investigators' objectives, methods, findings and conclusions.

In general, it was found that the carrying capacity research focused on the measurement of flow velocities and rates in buildings of various types, as well as in stadia and train stations. Two overall objectives included the construction of predictive models of building egress, and the establishment (or evaluation and acceptance) of egress facility design standards. Accordingly, researchers concentrated on the various components of egress routes, and evaluated differences in flow characteristics between level versus inclined paths (stairs, ramps), along corridors versus through doors, upward versus downward travel on stairs, etc. Consider the following investigations:

3.2.1 NFPA (pre-1920)

During the immediate pre-1920 period, the NFPA's Committee on Safety to Life was organized (see NFPA, 1917). In response to several disasterous fire incidents, in which the deaths of large numbers of persons were attributed to inadequate exit design, the Committee was charged with the task of developing recommendations for the number of occupants permitted on the floors of buildings. The earliest deliberations focused on the exiting problem in factory buildings, and attempts were made to account for construction type, hazard category, maximum allowable escape time, and stair capacity.

It should be noted that the Committee did not, itself, conduct empirical research, *per se*; but it was apparently the first professional body to organize specifically for the purpose of systematically evaluating anecdotal accounts of emergency egress activities, in relation to informal studies which were being conducted at the time in various occupancies. It should be further noted that the Committee's work came in the wake of the Nation's earliest legislation specifically devoted to life-safety from fire in buildings: the New York State Factory Laws (1914), and the Wisconsin Building Code (1914).

Although NFPA's initial involvement in life-safety design regulation included neither the conduct of specific empirical investigations, nor the development of a comprehensive research program, its inclusion here seems justified for two reasons. First, the early meetings of the Committee on Safety to Life appear to have formally adopted a physical-science approach to building egress in which building occupants, like

water, gas particles or ball bearings, were assumed to respond immediately, and to be effected only by spatial configuration and density, during the actual evacuation process. Moreover, since interpersonal influences on an occupant's behavior, and the influence of affective responses to emergency cognition in humans were ignored, the philosophy further legitimized consideration only of the "safe end" of the fire event (i.e., the specially protected segments of evacuation routes).

Second, by legitimizing its conceptualization of the emergency egress problem in relatively specific terms, the Committee set the stage for future research on all aspects of life-safety in buildings. That this has indeed been the case is amply born out by other research reviewed in this section of the current report.

Several conclusions relative to the pre-1920 egress state-of-art resulted from the early Committee deliberations, and have been critical to the formulation of the present day posture toward exiting regulation and research. These include the notions that:

(a) for non-fire resistive buildings without horizontal exits, only so many persons shall be permitted to occupy any floor as can find refuge within stair enclosures;

(b) for fire-resistive buildings, the number of persons allowed per floor may be in excess of stair capacity;

(c) maximum escape time may be assumed to be a function of the number of persons passing out of the exit door, as follows:

$$ET_m = 4/3\ [\#\text{ of persons}/22''\text{ unit*}]$$

$$+\ [\text{time required to get to stairs, in seconds}]$$

* above the first floor

(d) a useful guideline for stair design is to assume an average flow rate of 45 persons/minute/22" width unit (1.35 persons/sec/m).

3.2.2 NBS (1935)

The principal objectives of the 1935 exit review conducted at the National Bureau of Standards were to study exit requirements, develop code provisions, and gather facts about exit conditions found in actual buildings. The resulting comprehensive assessment was a direct outgrowth from the foundation laid earlier by the NFPA, with the NBS effort attempting to validate the original recommendations, and to expand egress research beyond the domains of factories and schools.

The NBS effort primarily involved of two types of investigation: First, a field study was conducted in a wide variety of occupancies in

an effort to record exit conditions actually found, and to measure flow rates through doors, corridors, and on stairs. Measurements were made under non-emergency conditions, during periods of normal occupancy. The field study yielded the following results:

(a) detailed exit conditions, and dimensions in examples of the occupancies surveyed were reported;

(b) discharge rates (as measured at doors, and at arbitrarily selected points along stairs and corridors during periods of normal occupancy) were found to vary somewhat across occupancies;

(c) discharge from ramps was found to be faster than from stairs;

(d) the rate of discharge was found to be relatively high in narrow passages as compared to wide ones;

(e) discharge rates were also found to vary as a function of story height, riser-to-tread ratio, and the walking habits of occupants.

Second, an opinion survey was undertaken. This involved the distribution of questionnaires to building professionals, and a content analysis of relevant articles in architectural magazines. The general objective of the opinion survey was to assess design professionals' feelings about the severity of fire safety regulations. It was found, almost without exception, that architects considered the egress regulations of the time to be much too severe and restrictive. When explaining their opinions, many architects mentioned their belief that building regulations were too arbitrary, and not based upon sound scientific evidence.

The general recommendations of the NBS report reaffirmed, and implied concurrence with, the building regulations promulgated earlier by the NFPA. and 60 persons/min/22 inch exit unit (1.35 and 1.79 persons/sec/m) down stairs and through doorways, respectively. Moreover, the general applicability of these regulations to a wide variety of occupancies was implied.

3.2.3 K. Togawa (1955)

The seminal work of Togawa in Japan is the most detailed and comprehensive analysis of egress carrying capacity based on a physical-science model. Togawa's objective was to survey walking velocities and flow rates on stairs, through doors, and along corridors in department stores, apartment houses, theaters, museums, hotels and commuter train stations.

Togawa conducted field studies at the various sites, observing inhabitants during periods of normal occupancy. Both individual and group movement patterns were observed to measure the number of people passing between two arbitrarily fixed points in space, as well as the time required for travel between the two points. Major findings included the following:

(a) Flow rates often varied as a function of occupancy; but such other factors as time of day, the age and sex of occupants, and the type of footwear worn, appeared to have little meaningful influence.

(b) For individuals walking on stairs, stair width was found to be an ineffective measure of flow rate. However, the tread-depth dimension appeared to be most critical, and the individual's pace was the only effective measure.

(c) For group movement on stairs: (1) travel time was found to be an inverse function of staircase angle and story height; (2) travel velocity was generally estimated to be 0.5 m/sec; (3) walking time up or down stairs was estimated at "4H" [i.e., 4 x (story height), in seconds]; and (4) flow rates were approximately 1.5 persons/sec/m through doorways, and 1.3 persons/sec/m on stairs.

Togawa derived predictive equations from the field data he gathered, and demonstrated for a commuter rail station during rush-hours that his mathematical model could estimate actual egress times.

Finally, Togawa was the first to describe "arch formation", the process by which a large group gathered at a doorway begins to admit persons through the opening.

3.2.4 J.J. Fruin (1971)

The above paragraphs maintain that a small number of studies, particularly those by the NBS in 1935, and by Togawa in 1955, were influential in establishing an attitude toward research on egress. This attitude influenced Fruin, who studied pedestrian movement on stairs, along corridors, and through doors. His specific goals were the measurement of pedestrian volume (i.e., density), walking velocity and flow rate, spacing, conflict and queuing.

Methodologically, Fruin's work may be construed as a replication of the earlier studies on carrying capacity. In particular, he conducted field studies in public buildings of various types, where actual users were observed during periods of normal occupancy. Pedestrians were timed during their journey between arbitrarily fixed points along various paths, as had been done by Togawa. In addition, Fruin included more general observations of pedestrian movement behavior.

For level passages and doorways, Fruin found that:

(a) reverse and cross-flow traffic conflicts did not substantially reduce either pedestrian volume or speed;

(b) pedestrians tended to remain between 1 and 1.5 feet (.305 to .457 m) from the sidewalls of passageways;

(c) maximum average peak flow volumes were approximately 25 persons/min/foot (1.367 persons/sec/m);

(d) hands-on-shoulders evacuation yielded better flow characteristics, and a better "psychological climate";

(e) maximum average flow capacities were attained when the pedestrian volume approximated 5.0 sq. ft./person (0.467 sq. m/person);

(f) as traffic density increased, pedestrians were more likely to close their ranks by reducing their longitudinal, rather than their lateral spacing;

(g) queues developed when the flow-rate through a door was less than that of the passageway;

(h) for freely-swinging doors, 40-60 persons passed per minute (0.67-1.0 persons per second).

Concerning movement patterns on stairways, Fruin found that:

(a) movement velocities were faster going down than going up;

(b) males traversed stairs more rapidly than did females;

(c) for both upward and downward travel, velocity decreased as the angle of incline increased;

(d) density appeared to have little effect on traffic flow;

(e) for "normal" movement patterns on stairs, 7-8 sq. ft./person (0.651-0.744 sq. m/persons) was required;

(f) as the density decreased on stairs, so did the variability of movement velocity;

(g) crowding on stairs was inferred when the flow rate reached 18.9 persons/min/ft. (1.033 persons/sec/m), by which point queuing was extremely likely.

3.2.5 I. Peschl (1971)

Another recent example of carrying capacity research based on the traditional physical-science model was provided by Peschl, who investigated the capacity of door openings during simulated "panic" situations. Peschl's work, however, differs from that of other researchers in that he conducted a laboratory, rather than a field experiment.

Peschl simulated various doorway conditions in the laboratory, and then asked groups of varying numbers to press against the doors until all persons moved through. Subjects were student volunteers, and large group experiments were assumed to be analogous to, and representative of, "panic" conditions in real building emergencies.

Peschl found that:

(a) often, after passing through the doorway, persons fell or stumbled (this was most acute in the large group experiments);

(b) the wider the doorway, the smaller was the probability of arch formation, and the greater was the variability in flow rate;

(c) stable arches formed at openings of 1.2 m, and the frequency of arch formation increased for narrower door widths;

(d) openings of 0.86 m produced very stable arches, and crowd passage was almost impossible;

(e) for a 0.6 m doorway, the rate of exit for groups was nearly zero, due to the very frequent occurrence of arch formation;

(f) movement through the doorways was found to be 3 times as fast for an "exponentially" curved outlet design, and 2.5 times as fast for a rounded wall, as compared with a doorway in a straight wall;

(g) rapidity of movement through doorways decreased as the numbers in a group increased;

(h) the probability of arch formation decreased, the smaller the group;

(i) the rate of exiting for a group was a linear function of doorway width;

(j) "pulsating" flow often resulted, since arches were self-dissolving; a plot of exit rate as a function of time yielded a saw-tooth form.

On the basis of his findings, Peschl concluded that human beings may be assumed to behave, in egress during panic, as granular particles flowing from bins. Accordingly, he recommended that floors in egress ways be sloped toward exit doors, and that a safe minimum door width would be 1.2 m.

Peschl's approach and conclusions represent the strongest reliance on a particle-behavior explanation of human behavior in building emergencies to be found in the literature.

3.2.6 L.F. Henderson (1971)

While Peschl advocated the "granular", or particle model, Henderson introduced a far more rigorous form of analysis. Henderson suggested, *a priori*, that the movement of human crowds should be analogous to the propogation of gas particles. Accordingly, he sought to demonstrate that crowd movement could be described by the classical Maxwell-Boltzman gas model.

Henderson distinguished between low- and high-density crowd flow, and suggested that each has a counterpart in a model of particle movement. In particular, while low-density crowd flow could be treated as a gaseous medium, high-density flow could be construed as a fluid. His application was confined to an experiment in "low-density" human crowd movement.

Henderson's investigation primarily involved two phases. First, he observed human movement patterns in actual settings, and made measurements of directional and velocity vectors. He studied several settings to

test various implications of the gas theory: College students on a campus thoroughfare, adults in a traffic intersection, and children in a playground.

Second, he ran computer-simulations using the Maxwell-Boltzman equations to generate "particle behavior". He then analyzed his data by testing for agreement between movements in real environments, and those predicted by the model.

Interestingly, the Maxwell-Boltzman gas model did predict real-world crowd measures rather accurately. Of greater interest is the fact that Henderson attributed much of the variance between the two sexes to differences in their walking habits (males were found to move faster than females).

3.2.7 S.J. Melinek and S. Booth (1975)

The principal objective of these investigators was to review and interpret crowd movement and building evacuation data, for the purpose of modeling evacuation time. This primarily involved existing data bases, and focused on emergency egress from health-care facilities.

Melinek and Booth made the following observations on the basis of their review of the carrying capacity literature, and as a result of their modeling experience:

(a) escape becomes more difficult as visibility is reduced due to smoke;

(b) evacuation time depends upon how alert occupants are, and their ability to respond to an alarm;

(c) the age and sex of individuals in a crowd has little bearing on velocity (in contrast with Henderson's observations), since the speed of a group is determined by pressures exerted among all its members;

(d) there is less variation in the speed with which stairs are ascended, than descended;

(e) the normal capacity for corridors appears to be 1.5 persons/sec/m (for corridors between 1 and 3 m wide);

(f) for unimpeded movement ("free-flow), a velocity of 1.3 m/sec may be assumed;

(g) for densities of up to 1 person/m^2, the speed of an individual is equal to the "free-flow" velocity;

(h) flow-rate maxima appear at densities of between 1-5 persons/m^2, and at higher densities, congestion results and flow rates decrease;

(i) for upward-sloping passages, velocity is reduced by 2% per degree of grade;

(j) for downward-sloping passages, velocity increases for small grades, and decreases for larger grades;

(k) maximum downward velocity is generally found to occur with gradients of approximately 7%;

(l) normal capacity on stairs appears to be 1.1 persons/sec/m;

(m) as crowd density on stairs increases, the flow-rate reaches a maximum level, and then decreases;

(n) bends and corners do not appear to reduce flow-rate on stairs;

(o) arch-action becomes conspicuous when the flow-rate at an exit reaches 1.8 persons/sec/m;

(p) the frequency of arch formation is inversely proportional to the square of the exit width.

On the basis of their reviews, Melinek and Booth developed equations for the computation of evacuation time, which are essentially similar to those offered earlier by Togawa. They also offered several design recommendations:

(a) panic may be reduced by: (1) facilitating smooth egress flow, (2) providing places of safety within buildings, (3) providing emergency communication systems within buildings, and (4) providing emergency lighting;

(b) the smallest recommended exit width is 0.76 m (as compared with 0.53 m required by British codes, and 1.2 m recommended by Peschl);

(c) the installation of mirrors should be avoided along exit routes, where they could seriously mislead and confuse evacuees.

3.3 Investigations of "Carrying Capacity" which Question the Physical-Model Foundation

We shall now discuss studies of egress carrying capacity which tend to reject the physical-science models as sufficient conceptualizations. In general, research in this category was conducted in such real-world settings as subway stations, office buildings, and hospitals. As in the case of those investigations examined above, the studies reviewed here emphasize the measurement of flow-rates, velocities, and evacuation time in facilities of various configuration. Again, the participants were not exposed to life-threatening toxants and other stimuli of actual fires. However, attempts were made to

structure field experiments, rather than to simply observe flow patterns under the routine conditions of normal occupancy.

In not every instance did the authors cited below overtly suggest that their data call into question the physical-science foundations for design regulation. However, where this did not occur, it is reasonable to infer from their findings that they questioned the traditional conceptualization of the emergency egress problem.

3.3.1 London Transport Board (1958)

The flow of passengers in London subway stations was studied by means of observations made of the normal use of these facilities. The numbers of passengers passing through selected footways within a fixed time period were recorded. In addition, population densities and movement velocities were measured. In a parallel study, controlled experiments were conducted at a boys' school, in which rate-of-flow was measured under conditions of varying density in corridors.

The following results were reported:

(a) in general, flow-rates on level passageways approximated 1.48 persons/sec/m;

(b) flow-rates on stairs approximated 1.04 persons/sec/m (ascending), and 1.15 persons/sec/m (descending);

(c) for footways wider than 4 ft (1.22 m), the "lane" effect was of little importance;

(d) flow was often 50% greater through short passageways (corridors less than 10 ft long (3.05 m)), than through longer ones of equal width;

(e) two-way traffic flow yielded no substantial reduction in total flow;

(f) after the installation of a center handrail, the velocity on a 6 ft (1.83 m) stairway was reduced from 2.17 persons/sec. to 1.75 persons/sec.

(g) although the installation of center handrails effectively reduced the number of available lanes from 3 to 2, actual flow was not reduced by this ratio.

(h) queues did not tend to form at bends or corners;

(i) minor constrictions in passageways had no effect on capacity, but tended to increase overall journey time for individuals;

Two conclusions resulted from observations made during this study, which specifically questioned the traditional particle models of egress behavior. First, the London Transport Board investigators concluded that pedestrian systems must be studied in their entirety, since different segments may contribute differential degrees of constriction. This clearly contrasts with most carrying capacity research, which designates arbitrarily selected segments for detailed analysis, and then generalizes results to a wider range of conditions.

Second, the researchers concluded that the mechanism of crowd-flow (albeit in subway stations) could not be considered analogous to either liquid or gaseous flow in pipes. Instead, they found the speed of passenger flow, with respect to density, to be represented by an equation which, in the important middle ranges of density, reduces to the form:

$$(\text{velocity}) \times (\text{density}) = \text{a constant.}$$

The investigators argued that this is not analogous to liquid flow, since a liquid is virtually incompressible, and its density may be considered as a constant independent of velocity.

3.2.2 J.L. Pauls (1975)

Pauls documented the movement of people on exit stairs and other egress facilities under various circumstances. Of major importance is his study of some 40 evacuation drills in high-rise office buildings in Canada. Pauls distinguished between two types of evacuation: total evacuation, in which all occupants are presumed to attempt egress simultaneously via the exit stairs; and phased evacuation, in which the various floors are cleared according to some prearranged sequence.

The principal variables evaluated by Pauls included density and personal space utilization on stairs, speed of descent, and evacuation time. Data collected during fire drills included voiced-taped observer comments, taped background sounds, and visual records of stair and corridor activity. It was generally assumed that the drills occurred without the prior warning of building occupants.

On the basis of his field studies, Pauls urged that the traditional assumptions which govern stair design in building regulations be reconsidered. He found, for example, that:

(a) Evacuees did not walk in a highly regimented fashion, shoulder-to-shoulder, nor even in staggered files. Side-to-side body sway, individual concern for interpersonal separation, and varying need for handrail support all influence the utilization of exit stairs by evacuees.

(b) Speed of descent on stairs tended to be more variable, and generally lower, than architects had been led to believe by the traditionally-

assumed flow-rate of 45 persons/min/22" stair width unit (1.35 persons/sec/m).

(c) Evacuation time in total-evacuation drills appeared to depend upon (1) total building population and (2) available stair width. A 10-story building with 100 occupants per width unit could be evacuated in less than 5 minutes (+/- 20%). By contrast, a 30 story building with 1,000 occupants per width unit might take more than 30 minutes to evacuate.

These estimates derive from studies in which evacuees had prior drill training, and were allegedly unaware of the reason for the evacuation (i.e., that it is only a drill). In addition, trained supervisory personnel ("floor wardens") were present on each floor.

Pauls' analysis of phased-evacuation methods diverges even further from the "particle" approach to emergency egress. According to his observations, phased evacuation required trained supervisors and emergency communications systems. The efficient use of exit stairs was seen to depend not only upon evacuees' movements, but also upon the organization and management of the evacuation.

3.3.3 I. Appleton and P. Quiggen (1976)

These investigators simulated emergency egress procedures at a British hospital. Data gathered from the mock evacuations included patient-preparation times, travel times, and travel speeds. The chief objectives of the study were to recommend improvements to decrease total evacuation times, and to develop a general model of evacuation for hospitals.

During the simulations, professional actors roll-played both ambulatory and non-ambulatory patients. Two potential fire situations were evaluated: a daytime incident, with all staff members on hand, and a nighttime fire, during which only a skeletal staff was present. The simulated escapes were filmed, and special attention was paid to such activities as: patient preparation, travel across the ward, shunting patients through the exit, movement on stairs, and the staff members' return to the ward to assist other patients.

As did Pauls, Appleton and Quiggen suggested factors operating during fire situations which cannot be adequately explained by particle models. Examples include stress and fatigue, which influenced the performance of staff members under emergency stress, as well as indecision, which occurred when alternative exits were necessary.

3.4 Investigations of Egress Signage, Emergency Lighting, and Visibility Through Smoke

Focusing on neither emergency evacuation behavior nor the carrying capacity of various facility designs, a small body of experimental

literature has dealt with the problems of exit sign perception, egress path lighting, and visibility through smoke. Examples of this research generally cluster into three categories: Japanese research on human behavior in smoke-filled environments, U. S. Naval investigations of emergency evacuation procedures on board Naval vessels, and experiments conducted by the Federal Aviation Adminstration's Office of Aviation Medicine. Several examples are considered below.

3.4.1 Y. Watanabe, K. Nayuki and K. Torizaki (1973)

These researchers observed the actions of firemen in smoke. Experiments were performed in mine safety training pits. In a variety of smoke densities, subjects (equipped with breathing apparatus and a portable light) walked along designated courses, which included horizontal and inclined paths. During the experimental period, subjects' walking speeds and respiratory rates were measured. In general, it was found that:

(a) walking speed decreased as smoke density increased, until a point was reached at which speed was nearly constant, and equal to that in total darkness,

(b) as walkers became experienced with the course, their walking speeds increased by up to 0.5 m/sec on the horizontal, and by up to 0.3 m/sec on a stair,

(c) walking speeds were lower at corners than along straight portions of the course,

(d) when subjects fell down in the smoke, they tended to lose their sense of direction,

(e) subjects least accustomed to both smoke and the route showed the highest respiratory rates.

3.4.2 S. Tashida (1975)

Tashida conducted further experiments on the effects of smoke densities on human walking performance, employing subjects thoroughly familiar with the interior space used for the experiments. Tashida found that:

(a) As smoke density increased, walking speed decreased. But as smoke density reached a certain point, the walking speed reached a fixed level, and was no longer affected by smoke density. Consider these subjects' reports: "...even when a portable light was used, observations became difficult, until it finally was a matter of shining the light at one's feet, and the speed was reduced accordingly." "Finally, when the smoke density reached

the point where the light would barely illumine one's feet, I proceeded by reaching out to feel the wall at my side." At that point, walking speed was influenced more by the use of the wall, than by smoke density, per se.

(b) Subjects occasionally stopped along the path in order to search for the lighted objective.

Tashida posited (quite believably) that persons making emergency escapes in a smoke-filled environment become anxious, especially when the visibility of wall and floor surfaces is reduced beyond a certain level. In cases where occupants are not familiar with the environment, this is believed to contribute to "panic".

In another similar experiment, Tashida found that:

(a) where visibility was approximately 5 m, some 20% of the subjects returned to the starting point,

(b) where visibility was estimated to be 10 m, however, only 10% returned.

On the basis of these results, 10 m was recommended as the minimum visibility range for persons in novel environments.

3.4.3 P.M. Edmondo and H.T. Macey (1968)

These researchers conducted investigations into the use of illuminated directional markers for emergency egress from ship compartments. Their objectives were to determine the visibility of various light intensities in dense smoke, and to evaluate the effectiveness of lighted devices as directional markers.

Two experiments were conducted. In the first, the visibility of different light-emitting units through varying smoke conditions was measured. These units included quartz-iodine lamps, standard Navy handlanterns, xenon flashers, and illuminated exit signs.

The second experiment was designed to simulate actual emergency conditions, and to determine the optimum placement and directional capabilities of light sources.

On the basis of these experiments, it was found that:

(a) The quartz-iodine lamp had the shortest detection distance of the various lamps tested. The handlantern and xenon flasher were nearly equal in detection distance.

(b) The handlantern was found to be the best directional device. The 2 ft. (0.61 m) mounting height above the floor level, with a 6

(0.61 m) mounting height above the floor level, with a 6 ft. (1.83 m) separation between lanterns, and with the light beam aimed parallel to the direction of oncoming traffic.

3.4.4 J.D. Garner and D.L. Lowrey (1976)

A laboratory experiment wad conducted in order to compare a variety of commercially available exit signs and markers for aircraft cabins. Both the light output and smoke penetration characteristics of such units were evaluated.

Ten different signage units were obtained, and measures were made of their average background brightness, average letter brightness, and letter-to-background contrast ratio. Measurements for each light were recorded at one-foot (0.305 m) intervals, up to 6 feet (1.83 m), in clean air and in smoke, in a specially constructed chamber. Light transmittance over a 6 ft. distance was used as the smoke density criteria.

Garner and Lowrey found that:

(a) all examined light units diminished in output in smoke at a proportionate percentage drop in their initial brightness;

(b) higher initial brightness resulted in higher levels when measured through a 90% smoke medium;

(c) at some point, however, there appeared to be a diminishing return, since the increases in power requirements did not appear to be justified by the slight increases in illumination.

3.5 Investigations of Occupants' Responses to Actual Fire Emergencies

Quite recently, several investigators have attempted to account for human psycho-social parameters, and to examine emergency behavior in the context of real fire emergencies. In these studies, facility design per se was not at issue. Rather, researchers emphasized the need to understand the behavioral patterns which account for the variance in egress success rates (Wood, 1972; Haber, 1977; Bryan, 1976; Lerup, 1976). Principal examples of this literature are explored below.

3.5.1 P.G. Wood (1972)

Wood had fire department personnel interview victims at the scene of fire incidents. Nearly 1,000 fires were investigated in the United Kingdom. Approximately 50% of these occurred in single-family dwellings, and another 22.7% occurred in factories and shops. About 2% involved more than 250 occupants.

In preparing his interview schedule, Wood was concerned with the following issues:

(a) how occupants first became aware of the fire;

(b) the location of occupants at the time of ignition;

(c) the first, second, and third actions taken by occupants, after being alerted to the fire;

(d) whether, and how, occupants attempted to leave the building;

(e) whether occupants had difficulty moving through smoke;

(f) the location of occupants upon arrival of the fire department.

Wood found that most persons interviewed became aware of the fire's existence either when they actually saw smoke, or through having been alerted by others. A few respondents indicated that they were initially alerted by the sight of flames, or by hearing distant shouts. Still others said that vague noises, fire alarm signals, and increases in ambient heat accounted for their initial alerting.

The following accounted for about 80% of all first actions reported: Fire-fighting, calling the fire department, investigating the fire, warning others, evacuating oneself, and evacuating others.

Fighting the fire, "inaction", calling the fire department, leaving the building, and shutting doors accounted for about 60% of all second actions, and approximately 73% of all third actions reported.

Most actions were found to be similarly distributed across the three sequential categories. An interesting exception is "inaction". This activity was virtually absent as a first action, was found to account for some 15% of the second actions taken, and was finally noted to account for nearly half of all third actions reported.

Actions taken were also evaluated against various other factors. For example, Wood found that:

(a) significantly more people left the building when cues were ambiguous and confusing than when cues were unambiguous;

(b) fire-fighting was more likely to occur as a first action when cues were clear;

(c) investigation increased in direct proportion with proximity to the fire;

(d) calling the fire department was less likely the farther one was from the fire.

Moreover, it was noted that:

(e) leaving the building as a first action was more likely when the fire was judged to be serious;

(f) fire-fighting became less likely when the fire was judged to be serious;

(g) there was a greater tendency to warn others, when the fire was judged to be serious.

It was also found that familiarity with the building did not correlate with the directness and immediacy with which a person left the building. However, persons who were familiar with the building;

(a) were more likely to call the fire department;

(b) were more likely to fight the fire.

More people were found to leave the building immediately when smoke levels were minimal. In contrast, immediate egress was less likely for persons who had previously experienced building fires.

Sex differences were also found to influence emergency actions taken. For example, women were less likely than men to fight the fire, or to take other steps to minimize the actual danger. They were more likely than men to warn others, leave immediately, or request assistance.

3.5.2 J.L. Bryan (1976)

Replicating Wood's field study, Bryan attempted to describe the behaviors of fire victims in incidents in the Washington, D. C., vicinity. As with Wood, Bryan focused upon reports of action patterns, and correlated them with such other factors as sex differences, mode of initial alert, and prior experiences in building fires.

Bryan generally corroborated Wood's findings on issues concerning mode of initial alert, reasons reported for not leaving the building, reasons reported for re-entry into the burning building, and sex differences in re-entry behavior.

However, findings reported by Bryan failed to corroborate Wood's concerning first action as a function of previous fire experience, and first action as a function of sex. Regretably, data reported by Bryan were not always presented in a format consistent with Wood's. Consequently, opportunities for comparison along the widest possible variety of factors, were lost.

3.5.3 G.M. Haber (1977)

A similar research strategy was employed by Haber, who interviewed victims of fatal fires in total-care institutions. These included

hospitals, nursing homes, and a home for the aged. Haber's principal objective was to determine how social organizations behave before, during and after fires in such facilities.

It was found that most of the buildings surveyed met all the applicable construction codes, and that they had not been criticized as fire hazards. In addition, no relationships were found between building size, fire-fighting equipment available, and the number of fatalities.

Rather than building or floor "size", the social structure and institutional organization of floors emerged as critical factors. In five of the seven fires investigated, the room of origin was in the extreme corner of the fire floor, far removed from the nurses station. It was also found that the occupants of such corner rooms tended to be the most deviant and chronically ill patients on the floor. Haber suggested that since these individuals tend to be ignored and neglected, a causal relationship between point of fire origin and certain institutional policies may exist. Further support for this argument stems from the additional findings that:

(a) "undersirable" patients were often assigned to rooms far distant from nurses' stations;

(b) the least attention tended to be paid to the most distant patients, in terms of surveillance and supervision.

While it was difficult to reconstruct the pre-fire socio-environmental structures in a post-hoc survey, Haber found some indication that the fires she studied were preceded by changes in normal routine, or the occurrence of some highly unusual problem in the building.

Concerning fire casualties, Haber found that:

(a) most deaths resulted from the inhalation of smoke and toxic gases, and not from burning;

(b) "panic" did not occur, and no deaths were attributable to panic-like behavior;

(c) those who died were exposed to smoke for at least five minutes;

(d) fatalities were found either opposite or near the room of origin, with no barrier between them and the smoke;

(e) several of those who died, though initially safe, delayed their evacuation to collect personal possessions, then opened their doors, and died in the smoke (according to reports).

In summarizing the human response to the fire environment, Haber further noted that:

(a) The fire was usually first noticed by a patient or nurses' aide, who actually saw flames or smoke. This person then alerted a nurse, and began shutting doors and evacuating patients.

(b) Male personnel, upon arrival at the scene, usually began fighting the fire themselves.

(c) Persons located outside the fire area usually responded with disbelief. This response changed, with the eventual confirmation of the fire.

(d) After the fire, all staff members were emotionally upset. Discussing the event with the interviewer seemed to relieve them.

(e) In general, staff members felt guilty about the fatalities. However, they believed that there was nothing different they could have done during the emergency.

3.5.4 L. Lerup (1975)

Lerup did not conduct empirical research, per se. Instead, he sought to identify patterns of human behavioral responses to fire situations, and of interactions between human behavior and fire migration.

As in the case of Haber, Lerup studied fires in health-care facilities. Unlike Wood, Bryan, or Haber, however, he was concerned with the "mapping" of relationships between human behavior and the spread of the fire. His mapping was based upon anecdotal accounts of fire events, such as the type frequently presented in Fire Journal. He considered fire spread in terms of discrete phases, or "realms" (internally consistent fire states which remain relatively stable over time), and critical events (discrete changes in fire development which mark the termination of one realm, and the onset of the next). Lerup also classified the behavior of building occupants in terms of decision points, or "episodes", such as fire-fighting, rescuing patients, seeking help, or escaping. Fire spread and occupants' movement patterns were shown superimposed on floor plans of the buildings in composite drawings, each of which represented one realm/episode combination. Many of the ideas for this approach were supplied by H. E. Nelson, of the National Bureau of Standards.

According to Lerup, the maps are useful in giving a pictorial representation of a fire, and might be used as a general means for recording and reporting information about fires.

3.6 Summary

In Part 3, we have described various kinds of empirical research on emergency egress. This was done to provide a basis for assessing the validity of past research as a foundation for exit design regulations. Accordingly, an effort was made to present investigators' objectives, methods, and findings.

Also, we have pointed out a dichotomy between research assessing the so-called "carrying capacity" of building exits, and research attempting to describe human responses under actual fire conditions.

In Part 4, we shall present evaluations of the empirical studies, which included:

(a) field studies of carrying capacity which implied particle-model explanations of human movement;

(b) field studies of carrying capacity which questioned such physical-science foundations;

(c) survey investigations of occupants' responses in actual fire situations;

(d) experimental investigations of exit signs, emergency lighting, and visibility through smoke.

4. ANALYTICAL ASSESSMENT OF THE EMERGENCY EGRESS TECHNICAL LITERATURE

The technical literature on emergency egress confronts those who wish to use it with a dilemna. On the one hand, the literature contains important and pertinent information. On the other hand, the information must be applied with considerable care, due to various methodological problems inherent in this area of research.

Perhaps the most pervasive caveat stems from the fact that data has been collected on human responses and capabilities in non-fire situations. The question therefore arises as to what extent these data can be used in the prediction of behavior in stressful fire situations? Unfortunately, there is little empirical evidence to help us. While we can be confident that egress behavior will be affected by the added stress, we cannot confidently predict the magnitude or the direction of the change. For example, in predicting pedestrian flow down a stairway, we might expect a decreased need for personal space during an emergency. This could increase the overall capacity of the stair. On the other hand, we might expect more eratic behavior on the stair, which could have the effect of decreasing its overall capacity. A possible hypothesis might be that the two effects balance each other. This would imply the use of flow rate data obtained quite easily during non-stressful situations. But this approach is neither supported nor refuted by available empirical data.

Each of the investigative approaches found in the emergency egress literature has its own set of methodological problems. Let us consider each of these approaches, which include:

(a) field based quasi-experimental research designs;

(b) post-hoc survey research designs,

(c) laboratory based experimental and quasi-experimental research designs.

The general assessment strategy is illustrated by the "analytical assessment matrix" (Figure 2). The assessment of the investigative modes includes a discussion of <u>general premises</u> underlying the approach, of <u>advantages</u> associated with the approach, and of potential <u>limitations to the utility of findings</u>. Finally, <u>a critique of specific egress investigations</u> is provided.

4.1 <u>Field Based Quasi-Experimental Designs</u>

These chiefly include the various investigations of carrying capacity which were conducted in real buildings, either under conditions of normal occupancy, or during evacuation drills.

4.1.1 General Premises

For field-experimental designs, some testable model of the system under study is often presumed to exist. Togawa, for example, described egress from buildings in terms of fluid or gaseous media which travel, according to deterministic physical principles, through pipes, ducts, and the like.

When inferences are drawn from the experimental data about the operation of real systems, it is further assumed that the model tested contains most relevant variables, and the correct interrelationships among these variables.

Similarly, it is assumed that variables studied have been properly defined operationally, and that it is technically possible to carry out such operations when making measurements in the field. In the literature on carrying capacity, for example, "egress behavior" has been quite narrowly defined in terms of such easily conducted operations as velocity and flow rate measurement.

Finally, a frequent general assumption is that the use of actual field settings as "laboratories" increases the external validity of the findings.

4.1.2 Advantages of Field Based Quasi-Experimental Designs

Depending upon the nature of experimental controls established in the field, moreover, data collected from field studies may be amenable to statistical analysis. Such analyses would clearly enhance the value of experimental results.

4.1.3 Limitations to the Utility of Findings from Field Based Quasi-Experimental Designs

In general, if an experimental situation differs appreciably from an actual situation, then generalizations from the experimental results to actual phenomena need to be justified. Thus, Pauls' research on fire drills may be generalized to similar fire drills, but not necessarily to real fires.

Many variables may be difficult to define operationally (e.g., "panic", anxiety, motivation, or even "safety"). When dealing with these, it must not be assumed automatically that measurements accurately or consistently reflect some universal notion of the construct in question (the problem of "construct validity"). Some investigators defined "egress behavior" velocities and flow rates. Certain observable performance characteristics were assumed to describe the entire complex behavioral system labeled "egress behavior". Broader studies of the egress problem (e.g., Breaux, et al., 1976), as well as anecdotal accounts of actual fires, suggest that this behavioral system involves perceptual and cognitive processes which could lead to quite different velocity and

flow rate outcomes. But the flavor and implication of such complexity is totally lost when so complex a construct as "egress behavior" is defined merely in terms of a few accessible performance measures.

Similarly, while other variables may be appropriately defined, their measurement may be extremely costly, difficult, or even dangerous if human subjects were used in actual building fire experiments.

4.1.4 Critique of Specific Investigations

In referring to the field investigations of carrying capacity as "quasi-experimental", the intention has been to emphasize their universal lack of either experimental controls or procedures for the random assignment of subject to conditions. While these features detract from the validity of any causal inferences drawn from research results, they may not seriously challenge the usefulness of non-causal correlations or trends suggested by the data. There are, however, issues of much greater concern in the evaluation of this segment of the technical literature.

For example, although some investigators made specific references to the applicability of certain models to the study of building egress (e.g., references to particle-models by Togawa and Peschl), they neither viewed their research as mechanisms for validating the particle-behavior assumption, nor did they otherwise question its validity. These models were in fact used, however, as a framework for conceptualizing the egress problem, and for explaining experimental results. But without an acceptable demonstration of the models' plausibility, the potential for drawing erroneous conclusions about the behavior of people in real fire situations is great.

In attempting to evaluate the findings and conclusions of the NBS (1935) research, the fact that the investigation did not simulate life-threatening conditions must be considered. The research methodology was also weak in its arbitrary selection of measurable discharge points, which bore little connection with a building fire "system", in which all segments of egress routes are interrelated, and in which building layout, fire phenomena, and occupants' response patterns may be presumed to interact continuously.

While there is no denying that Togawa's analysis of human flow rates in building was comprehensive, all the reservations discussed in connection with the carrying capacity literature apply to his analysis. In particular, it must be remembered that building inhabitants were observed only during periods of normal occupancy, and that they were not responding to life-threating environmental stimuli of any kind. Attempts to generalize Togawa's results to emergency egress during building fires (as has been suggested) requires the assumption that the stresses of the fire threat do not significantly hinder or facilitate egress performance.

In contrast, Henderson specifically sought to validate the Maxwell-Boltzman gas model as an explanation of human crowd movement. When interpreting Henderson's findings, however, it is essential to bear in mind that the humans observed were neither confined to the rigid environmental structure of building interiors, nor were they exposed to life-threatening elements. These, however, are factors which may be presumed to influence performance during building emergencies. As the Maxwell-Boltzman model was never empirically confirmed against real-world observations made under such circumstances, its use in the prediction of emergency egress behavior requires untested assumptions.

Equally serious difficulties stem from the fact that while meaningful trends may indeed reside within the data base, few attempts were made to employ analytical techniques capable of confirming their existence. Moreover, research strategies not truly amenable to sophisticated statistical analysis were frequently employed.

In summary, then, an analysis of the carrying capacity literature, based on certain investigative principles, yields little evidence supporting the application of this segment of the technical base to the development or evaluation of design regulations for emergency egress from areas directly exposed to fire and smoke. Instead, an important contribution of this literature appears to lie in the questions it has raised about the problem of emergency egress from buildings, and in the hypotheses and future research it may generate. In some cases, recent research on carrying capacity has led to an erosion of the traditional, narrowly-defined approach to research on this problem.

4.2 Laboratory-Experimental Designs

Within this category, the various investigations of visibility through smoke, and of emergency lighting and signage are addressed.

4.2.1 General Premises

For the most part, the premises underlying the conduct of laboratory-experimental research parallel those which guide their counterparts in naturalistic field settings (see Section 4.1.1). Of primary importance is the notion that experiments are usually designed for the purpose of testing models or theories about real-world phenomena. It is further assumed that;

(a) the model under test contains most relevant variables and relationships,

(b) the variables are properly defined operationally,

(c) these operations may be readily achieved, technically.

One factor which clearly distinguishes field-based from laboratory-based experimentation, however, concerns the question of external validity, as follows: When a field experiment is properly designed, such that environmental conditions during the experiment approach those inherent in the natural phenomenon, then the experimental results may usually be

assumed to generalize to real-world populations. However, when environmental conditions are set up in a laboratory, they are necessarily simplified, and essential components of the natural phenomenon may be sacrificed. The greater the discrepancy between the natural and laboratory environmental systems, the more likely it will be that generalizations from laboratory findings to real-world events are erroneous.

4.2.2 Advantages of Laboratory-Based Experimental Designs

Both theoretical and methodological advantages potentially accrue from laboratory experimentation. For example, this form of research permits the greatest opportunity for strict experimental control, whether accomplished through the pre-conditioning of subjects, their random assignment to experimental groups, etc. Much of the indeterminacy inherent in the emergency egress technical base stems from the virtually universal lack of just such experimental controls.

In addition, data obtained from well designed and tightly controlled experiments are readily amenable to statistical analysis. Again, the almost universal failure to develop a data base amenable to such analysis has contributed to the current inability to draw conclusions which are sufficiently unequivocal for regulatory purposes.

Finally, laboratory experiments are convenient. In comparison with field settings, laboratories usually are safer and more comfortable, and processes may often be scheduled to suit the experimenter's personal needs.

4.2.3 Limitations to the Utility of Laboratory-Based Experimental Findings

Again, these limitations generally parallel many of the issues addressed earlier in the context of the field-based experimental designs. As suggested above, the generalization of findings from experimental samples to real-world populations may also become problematic, especially when there is a questionable degree of verisimilitude between the laboratory and real-world systems.

4.2.4 Critique of Specific Investigations

In general, the experimenters discussed here did not explicitly describe their investigations as attempts to assess particular models of human perception or behavior. Rather, they attempted to deal on a piecemeal basis with various questions or hypotheses.

This tack is exemplified by the Naval and aviation experiments on signage systems, which sought to measure such quantities as detection level, without ever describing the phenomenon in terms of, say, the well-known "signal detection theory". Similarly, while the Japanese experiments on pedestrian movement through smoke appeared to suggest visibility maxima for corridors, no attempts were made to evaluate their findings against current psychophysical or physiological models. As a result, it becomes extremely difficult to determine the limitations on the applicability of such findings. Moreover, while such efforts

have added various bits of knowledge to the emergency egress data base, they contribute very little to the overall organization and strength of this base.

Even the validity of findings produced through these efforts may be called into question, when one considers important differences between the laboratory-experimental environments, and those of actual building fires. In one such experiment, human subjects were never actually employed. In those which did employ humans, moreover, performance measures were made on simplistic and relatively unrealistic tasks. In no cases did subjects believe that their lives were in any real danger, nor were they required to respond quickly to ambiguous or conflicting environmental cues. Moreover, no subjects were ever "taken by surprise." Very often, however, these are the kinds of factors and events which surround participation in actual building fires.

Needless to say, the issue of employing humans in building fire experiments or of subjecting persons to an actual injury or life threat is undesirable for a wide variety of reasons. Even exposing them to simulated threats might result in stress or psychic injury. This type of experimentation on emergency egress has not been undertaken in the United States. But to a very limited extent, such work has been done in Japan. However, the mere fact that humans were utilized does not in and of itself enhance the validity and usefulness of the research findings. Indeed, this could only result when well controlled experiments, in which the complexities of the real-world phenomenon are adequately simulated in the laboratory, are conducted.

In summary, there are two major difficulties with this segment of the technical literature. First, the validity of the findings is called into question because of the unrealistic qualities of experimental settings. Second, no advantage was taken of opportunities to relate experimental paradigms to the evaluation of explanatory models or theories of human responses in life-threatening situations. Although the aviation research conditions least simulated those which might actually be encountered in buildings, the Naval studies on board large ships appeared considerably more realistic. Neither approach, however, rivaled the Japanese work in building corridors and other similar situations. While results from these studies seem somewhat suggestive of occupants' behavior in smoke-filled environments, it must be reiterated that many other aspects of the life-threat were not simulated at all. Consequently, future research may derive considerably more benefit from the Japanese findings than might the design regulatory process, at least in the short run.

4.3 Post-Hoc Survey Research Designs

This category primarily includes investigations of actual fires, in which victims were interviewed.

4.3.1 General Premises

Post-hoc survey methods are often applicable both to analytical research programs in which formulated models are subjected to test, and to holistic studies which contribute to the preliminary phases of model construction.

In those cases where models have been formulated and are under examination, post-hoc case-studies of particular historical incidents are often considered useful for gathering supportive (or challenging) data. This is especially true in situations which, for practical purposes, preclude the conduct of well controlled experiments in field settings.

Where no models of the real-world system have been formulated, field surveys and post-hoc case-studies may be valuable in the identification of relevant parameters, conditions, and relationships which underlie and define such systems. This approach is exemplified somewhat by the investigations of Wood, Bryan, Haber, and Lerup. Wood and Bryan, for instance, operated under certain assumptions about the importance of such factors as differences in age, sex, prior fire experience, etc. They conducted lengthy post-incident case-studies at hundreds of sites in an effort to knit these factors into a more unified "picture" of emergency action sequencing. Eventually, a well formulated version of this picture, or model, may be formulated and subjected to more rigorous forms of empirical analysis.

4.3.2 Advantage of Post-Hoc Survey Designs

In the case of holistic research, where model construction (versus model confirmation) is at issue, field surveys and case-studies may be relatively informal. Since the strict logic required for the deduction and testing of hypotheses must often be relaxed or even bypassed, controlled environments need not be contrived, nor must "task performance", per se, be operationalized and measured. Rather, hypotheses are often formulated, tested, reformulated, and then re-evaluated, under "unclean" field conditions. The identification of trends is usually the desired outcome of holistic work.

4.3.3 Limitations to the Utility of Post-Hoc Survey Designs

Several problems inherent in the survey research approach are particularly relevant in the study of occupants' responses in actual building fires. In particular, the following should be noted:

Much of Haber's data was obtained in the form of open-ended verbal reports (as distinguished from scalar scores). Such reports may be adequate if the primary intention is to produce a narrative report on a particular historical event. However, where any form of tabulation or quantitative analysis is required, the intermediary task of translating qualitative statements into some numerical code must be performed. If this problem is not considered and solved during the early stages of research design and planning, when techniques for data acquisition and analysis are first developed, then specific evaluations of findings may be of questionable utility. For example, do the quantitative trends reflect occupants' perceptions and verbal reports, or do they rather mirror the researcher's biases, as these are built into his/her translation mechanisms? It would be interesting and extremely useful to note, for example, whether various other "experts" would draw inferences and conclusions similar to those of Haber, on the basis of the same raw data.

In addition, where case-studies or surveys involve either verbal reports or scalar responses, any interpretation of the results must recognize the potential for confusion likely to arise from diverse and often conflicting perceptions of given words, phrases, questions, etc. In the absence of validated questionnaire instruments (presently a key problem in the fire area), the data analyst may well wonder: whether the victim was responding to the question, as asked? Whether the respondent viewed the event in the same light as did the researcher? Whether the respondent's internalized subconscious model of the fire incident, based on his/her actual experience, was the same as the researcher's intellectualized (though often also subconscious) model?

Other difficulties are more tactical in nature. For example, if too long a time period is allowed to lapse between the occurrence of the actual event, and its investigation through post-hoc techniques, memory decrement may operate to reduce the validity of the data gathered.

Similarly, if victims have had ample opportunity to think about the event, to discuss it openly with others, or to read the anecdotal accounts, then the mediated version which is reported to the researcher may well differ from the actual occurrence. While investigators may take care to identify potential sources of such mediation (absent from the current technical base), it is not likely that they will successfully determine their actual impact on victims' reports. Again, Haber's findings may suffer from this problem, as might Lerup's analysis. In these cases, while it might be tempting to infer certain behavioral trends from the data, the actual validity and usefulness of the findings are themselves virtually indeterminate.

Conversely, if the event was traumatic or painful, too short a time lapse between the incident and its reporting may adversely influence validity, as well. In particular, emotional controls over victims' perceptions may act to produce erroneous, or distorted reports. This problem becomes especially acute in cases where the reports are solicited before respondents have had adequate time to "sort things out" in their minds. Examples of this threat are likely to be found in the studies by Wood and Bryan, who had fire-fighters question victims at the scene. Unfortunately, no attempts were made to assess the potential influence of this "shock factor," nor to accommodate the inconsistency of its effect across the population surveyed. For these reasons, the usefulness of data obtained by these investigators, except in the identification of the most general (and least informative) trends, may also be indeterminate.

4.3.4 Critique of Specific Investigations

In evaluating Wood's findings, several caveats must be considered. First, procedures used for gathering data during the immediate post-incident period are extremely sensitive to the emotional effects of the fire experience upon the reliability of the victims' reports. Also, if a period of time is permitted to lapse between the incident and the interview, memory decrement and cognitive distortion may impact on reliability quite similarly.

Second, while various behaviors were tabulated as being first, second, or third actions, Wood failed to assess interactions among these

actions. The more important (yet unasked) question would appear to be how, for example, a particular first action influenced the selection of subsequent behaviors?

Finally, it should be noted that the fires reported were primarily those in single-family dwellings, and Wood's original analysis made no attempt to distinguish among occupancies.

When considering the application of these findings to the design of egress facilities, it should be further noted that Wood didn't correlate occupants' behavior with physical aspects of either the building layout, or the dynamic qualities of the fire threat (as Lerup, 1975, has since accomplished). Thus, it is difficult to apply Wood's findings to building regulations or to building design criteria.

In general, Bryan made the same methodological errors that Wood made. One exception, however, was the reconstruction of action sequences during fires. Although Bryan also failed to assess interactive effects among behavioral increments, he did infer from his data patterns of action sufficient to aid in the formulation of hypotheses for future research.

Even though Haber, Wood, and Bryan dealt with somewhat different concerns, there appears to be some agreement among their findings (for instance, with respect to the issue of sex differences). Each of these investigators employed essentially similar techniques, and these are generally subject to the same caveats. As a result, the question arises as to whether their corroborative findings are indeed accurate reflections of actual events (and are consequently of value), or whether they are merely artifacts of the research methodology. The usefulness of this data base would be greatly served if such issues were addressed through diverse techniques. Post incident surveys, for example, could be cross-validated by means of experiments of the type conducted by Appleton and Quiggen.

Lerup's mapping procedure is more than just data-plotting, and it embodies a model of person-fire relationships. It implied that discrete transformations in patterns of human behavior are keyed to changes in the state of the physical environment, and that critical events which launch the fire system into a new realm will <u>simultaneously</u> generate decision points to which human occupants must respond.

Although Lerup appears to take this one-to-one relationship for granted, it remains an empirical issue. For example, it may be argued that decision-making behavior is somewhat stringently determined by environmental events when the latter are highly proximate, unequivocal, and salient. In building fires, however, it is apparent that many occupants are outside the immediate vicinity in which the critical events are unfolding, but are nevertheless receiving cues which vary quite widely in terms of their information content. It is also becoming more widely believed that where information is ambiguous, cognitive processes operate to create distorted perceptions of events within occupants' minds.

Since occupants may, therefore, potentially differ in terms of their perceptions of reality, a data-categorizing technique which is founded on the assumption that human behavior in fires is largely environment-determined seems somewhat unrealistic. Indeed, the resolution of this issue deserves high priority in any future research program.

Methodological difficulties of the type outlined above clearly detract from the utility of this segment of the technical literature base. Questions also arise, however, concerning the efficacy of applying knowledge about historical fires to the prediction of future situations, and to the solution of concommitant life safety problems.

When a fire occurs in a building, both the physical and human behavioral aspects respond in particular ways, forming a unique building fire system. Should a fire ever occur in the same building again, the various behavioral components are likely to unfold somewhat differently, creating a new, somewhat different, unique system. Theoretically then, no two fires in the same building will produce identical behavioral outcomes, and some distribution of events probably exists for the building. The fire which actually does occur in this building, therefore, may be viewed as a particular behavioral system sampled from the distribution of all possible systems.

Whether the actual fire produced among the most or the least likely outcomes is, at present, an indeterminate question. If it was among the most likely (and hence, most likely to occur again), then lessons learned from this fire may still be inadequate for dealing with future fires in similar buildings which occur at more extreme ends of the distribution. Or, if the outcomes were among the least likely, then such lessons may be of relatively little value, in terms of wide-scale design regulations for a building type. Although currently indeterminate, the future mitigation of this problem will depend upon the large-scale acquisition of reliable and valid data which explicate the fire-outcome distributions for various building types. Refer also to Figure 3.

In summary then, it must be first noted that the research conducted on occupants' responses in actual fires has produced very few data relating directly to the design of exit facilities in buildings. Rather, such studies have focused on the identification of sequential response patterns, virtually independent of physical design parameters. The analyst must further bear in mind that certain methodological and theoretical constraints associated with the post-hoc case-study approach may render the evaluation of such data interminate. Finally, when attempting to plan for future fires on the basis of historical cases, one must assume that:

(a) the outcome probability distributions are similar for all examples of the building type, and either:

(b) the case outcomes were the most likely, or

(c) all outcomes are sufficiently similar, regardless of their likelihood.

5. SUMMARY OF RECOMMENDATIONS

5.1 Recommendations Concerning the Technical Adequacy of the Available Empirical Literature

5.1.1 The Literature on Egress Facility Carrying-Capacity

Considering their restricted view of building evacuation, various investigators sought a rational way to measure or model the manner in which exiting facilities are in fact utilized by building occupants. The investigators assumed that the dimensions of exit path elements were the dominant controlling factors. This has resulted in a variety of recommendations relating to door and corridor width, maximum escape distances, and minimum stair provision. All researchers measured essentially the same egress parameters (e.g., flow rate), and while their interpretations occasionally differed, most presented similar data. All things being equal, this segment of the technical base should be useful in formulating or supporting regulations for egress facility design.

The obvious discrepencies between the work of Pauls and other investigators of carrying capacity should be taken into account. It must be noted, however, that Pauls' data have not as yet been replicated, while the other researchers have effectively replicated each others' findings since 1935. Moreover, studies by all these individuals share similar methodological and inferential caveats, as presented in Chapter 4 of this report.

On the basis of our assessment of the carrying-capacity research, we conclude that this literature is technically adequate for those applications in which the following assumptions are acceptable:

(1) pedestrian movement may be conceptualized in terms of physical models which describe the flow of gaseous or fluid material;

(2) the measurement of walking velocity, flow rate, and escape time sufficiently describes "emergency egress behavior." Psychological and social factors which might influence the emergency behavior of people need not be considered;

(3) investigation of the dimensional adequacy of exit facilities is not enhanced by the consideration of factors which dispose fire victims to actually utilize these facilities effectively;

(4) pedestrian behavior during periods of normal building occupancy, during drills, or in a laboratory situation sufficiently represents such behavior during an actual fire emergency;

(5) the measurement of pedestrian flow over selected paths (e.g., stairs, or corridor lengths) or bottlenecks provides a sufficient representation of occupants' behavior for evaluating entire egress routes.

5.1.2 The Literature on Emergency Visibility, Signage, and Lighting

The most serious limitation to the utility of this data base is that it cannot be generalized from controlled experimental settings, to real-world fire environments and experiences. Certain trends in the data do seem to suggest, however, that the limited application of particular findings, at least on a trial basis in actual buildings, may be useful. In this context, standards might be developed, validated, or advocated which concern exit sign lighting, coloration and contrast, minimum visibility distances in smoke-filled spaces, etc. These appear to involve the much more stable psycho-physical characteristics of humans, which are likely to cut across wide variations in social or cognitive structure. We conclude that this segment of the literature is technically adequate for applications in which the following assumption is acceptable: all the vital characteristics of real building fires are sufficiently replicated in contrived laboratory settings; subjects' responses in the laboratory therefore provide the experimenter with realistic impressions of occupants' behavior under actual fire conditions.

5.1.3 The Literature on Human Responses in Actual Fires

Although there have been a number of recent post-incident studies on the sequences of actions taken by fire victims while attempting to evacuate the premises, none of these have proven applicable to the generation of OSHA egress regulations. These studies have failed to adequately account for either the validity of the behavioral sequences reported by victims, or for the environmental and fire development factors upon which such sequences were dependent. The absence of an explicit concern for the channeling of evacuees to the exitways, or for the arrangements of alternate exit routes, leaves a gap in the availability of data to support regulations in these areas.

While many insights on the experiential qualities of the critical early moments of the building egress process are emerging from this research, the role of the environment, and the basis upon which it could be more effectively regulated, remains unknown. Consequently, we conclude that this portion of the emergency egress literature is technically adequate only for those applications in which the following assumptions may be accepted:

(1) case-study data may be extrapolated between diverse occupancy categories;

(2) case-studies of specific historical fire incidents are useful in the prediction of future fire outcomes, for a given occupancy;

(3) the design of exit facilities requires knowledge of how people respond to a fire alert, how they interact with other people, and of the development of decision sequences;

(4) unconfirmed trends apparent in data from non-experimental studies are applicable to the development of exit facility design standards;

(5) available interview data collected from fire victims are useful even though the potential impact of confounding affects (e.g., emotional distress, memory decay, the erroneous interpretation of victims' remarks) has not been determined.

5.2 Recommendations Concerning Specific Applications of the Available Technical Literature

Within the limits imposed by the assumptions discussed above, various segments of the emergency egress technical literature may prove applicable to specific problem areas. Let us consider such applications in terms of the egress scenarios and generic response patterns outlined in Chapter 1 of this report.

5.2.1 The Literature on Carrying-Capacity

Of the three major focal points in the egress literature, the empirical research on exit facility carrying-capacity appears to involve the most judgment and assumptions when applying the data. In particular, we recommend application of this data base only to those emergency egress design problems in which occupants may be expected to demonstrate:

(a) unambiguous threat perception;

(b) a high degree of familiarity with the building's circulation system and exit locations;

(c) a high degree of familiarity with emergency procedures; and

(d) an immediate, purposeful, and well-staged exiting response.

The more proximate the threat is to a group of occupants, the more likely we would expect failure in flow estimates derived from "hydraulic" or "gaseous" models. We therefore suggest that applications of the carrying-capacity data base be limited to situations in which building occupants are outside the immediately threatened zone, and removed from fire bi-products which might cause confusion or evoke non-adaptive emotional response.

5.2.2 The Literature on Egress Signage, Emergency Lighting, and Visibility Through Smoke

Not only is this segment of the empirical base more technically rigorous than that dealing with carrying-capacity, but it also appears more readily applicable over a broader domain of occupants' response patterns. Clarity of directional cues, and quality of other emergency information can make the difference between unambiguous direct egress behavior, and the more indecisive and delayed forms of exiting response. This data base has the potential of helping to reduce such ambiguity.

It must be emphasized that building designers and code officials cannot predict the exact course of events during any specific building fire. Consequently, designs based solely upon carrying-capacity data may fail whenever:

(a) threat perception is not as unambiguous as expected;

(b) many more untrained or new occupants, and visitors, inhabit the facility than were originally planned for; and

(c) the immediacy of the life-threat evokes non-adaptive behavioral responses.

In our view, the technical state-of-the-art of this segment of the egress literature seems sufficiently adequate to justify its application to the problem of reducing perceptual and cognitive ambiguity during the emergency exiting process.

5.2.3 The Literature on Occupants' Responses to Actual Fire Emergencies

When considering its technical adequacy, this portion of the emergency egress literature proved least applicable to problems of exit facility design or regulation. Its greatest potential, however, may lie in the description of emergency scenarios, the identification of response behaviors, and the exposure of frequencies with which these actually have occurred during building fires. We recommend the application of this data base not to emergency exiting design *per se*, but rather as a guide to the application of the more design-oriented research, and as a groundwork for continued exploratory investigations of the nature of human behavior during building fires.

5.3 Recommendations Concerning General Directions and Methodological Requirements for Future Research

5.3.1 General Directions for Research

On the basis of the detailed assessment of the existing data base, four general categories are recommended for definitive research applicable to the development of more responsive OSHA regulations for emergency egress. These are:

(a) Research on access to exitways, including considerations of travel distances and the spatial separation of alternative exits;

(b) Resolution of the discrepencies between findings by Pauls and other investigators of the carrying capacity of exitways;

(c) Continued research on egress signage, lighting, and visibility through smoke (e.g., the work at the Center for Building Technology, IAT, National Bureau of Standards, which is currently under the sponsorship of OSHA); and

(d) Definitive identification and description of emergency egress scenarios and response patterns.

In order to guide the development and conduct of specific investigations, additional recommendations are offered concerning research strategy and technique, methods of data analysis, and the validation of findings.

5.3.2 Strategy and Technique

(a) In reviewing case-study results, it is presently impossible to determine whether the specific outcomes of the actual fire were among the most or the least probable, nor whether the incident studied was truly "typical" of the type which might be expected more generally in the occupancy. Consequently, the degree to which case-specific findings are useful to occupancy-wide regulatory policy is questionable. A first step toward mitigating this problem will be the development of a data base which yields probability distributions for key fire-outcomes, as these are reflected for various occupancies. In this regard, it will be essential that "fire-outcomes" are construed to involve not merely egress time and exit utilization statistics, but events more telling of occupants' decision-making behavior, as well.

(b) Where investigations shall involve measurements made on human subjects, it is extremely important that the most salient qualities of actual building conditions are replicated accurately. If pedestrian movement is to be measured during periods of normal occupancy, then generalizations will rightfully be limited to the general case of "normal occupancy." Similarly, observations made during fire drills may be somewhat telling of human behavior during such drills, while shedding virtually no light on the effects of an actual life-threat upon occupants' responses. If ethical and moral codes ultimately preclude the conduct of realistic experiments utilizing human subjects, then such experimentation cannot be considered at all. But, experimental results derived from poor replications of actual building fire conditions may yield falacious and misleading conclusions far too often, rendering such an approach largely ineffective.

5.3.4 Validation

(a) Since the objective of empirical research will usually be to accumulate useful data, "reasonable attempts" should be made to replicate experiments and to validate, or to otherwise cross-check, the data. Particularly, the investigator must have some confidence that the variables named are indeed those that are measured, and that the research setting sufficiently simulates the kinds of experiences which would be expected in actual fire situations.

(b) Interpretations and inferences drawn from experimental or quasi-experimental research should be based on statistical analyses of the data. This should extend beyond the identification of trends, offering some measure of confience that variations are not merely methodological artifacts, nor chance occurrences.

(c) Where the data do not lend themselves to the more rigorous statistical tests, the evaluation of a given set of findings might involve the inferences and opinions of a panel of experts.

5.4 Conclusions

Current OSHA regulations governing the design of emergency exit facilities in buildings are based almost exclusively on carrying-capacity research reported in 1935. However, this segment of the empirical literature on exiting seems relevant to only a small, but vital, portion of the emergency egress problem.

Wherever a fire situation is rendered confusing and ambiguous for any building occupants, the direct egress patterns presumed by carrying-capacity researchers may occur with decreasing frequency. In these situations, ambiguity may be decreased through the provision of adequate directional information. While a technically adequate body of data addressing this subject has begun to emerge, current OSHA exiting regulations are not based on these recent findings.

No validated data were found pertaining to the role of the environment, nor of the development of the fire, in shaping the critical decisions that a person must make when responding to an initial fire alert. Moreover, no suitable technical data was found that supported current OSHA regulations on the maximum distances to protected exits, or on the provision of alternative means of egress (these regulations appear to be based upon the judgment of engineering experts). This lack of research exists despite the fact that a major portion of all fire deaths in buildings seem to occur while people are <u>trying to reach</u> a protected exitway or place of refuge.

Finally, an effort was made to consider various OSHA regulations in the light of available data bases. This analysis represents an initial attempt to key our recommendations for future research directly to specific problem areas within the regulations. This analysis is outlined in Table 1.

FOOTNOTES

(1) Public Law 91-596, 91st Congress, S.2193, December 29, 1970. The complete text appears in Appendix C of P.S. Hopf's useful handbook, Designer's guide to OSHA: a practical guide to the occupational safety and health act for architects, engineers, and builders (New York: McGraw-Hill, 1975).

(2) Occupational Safety and Health Act of 1970, Section 6(a)

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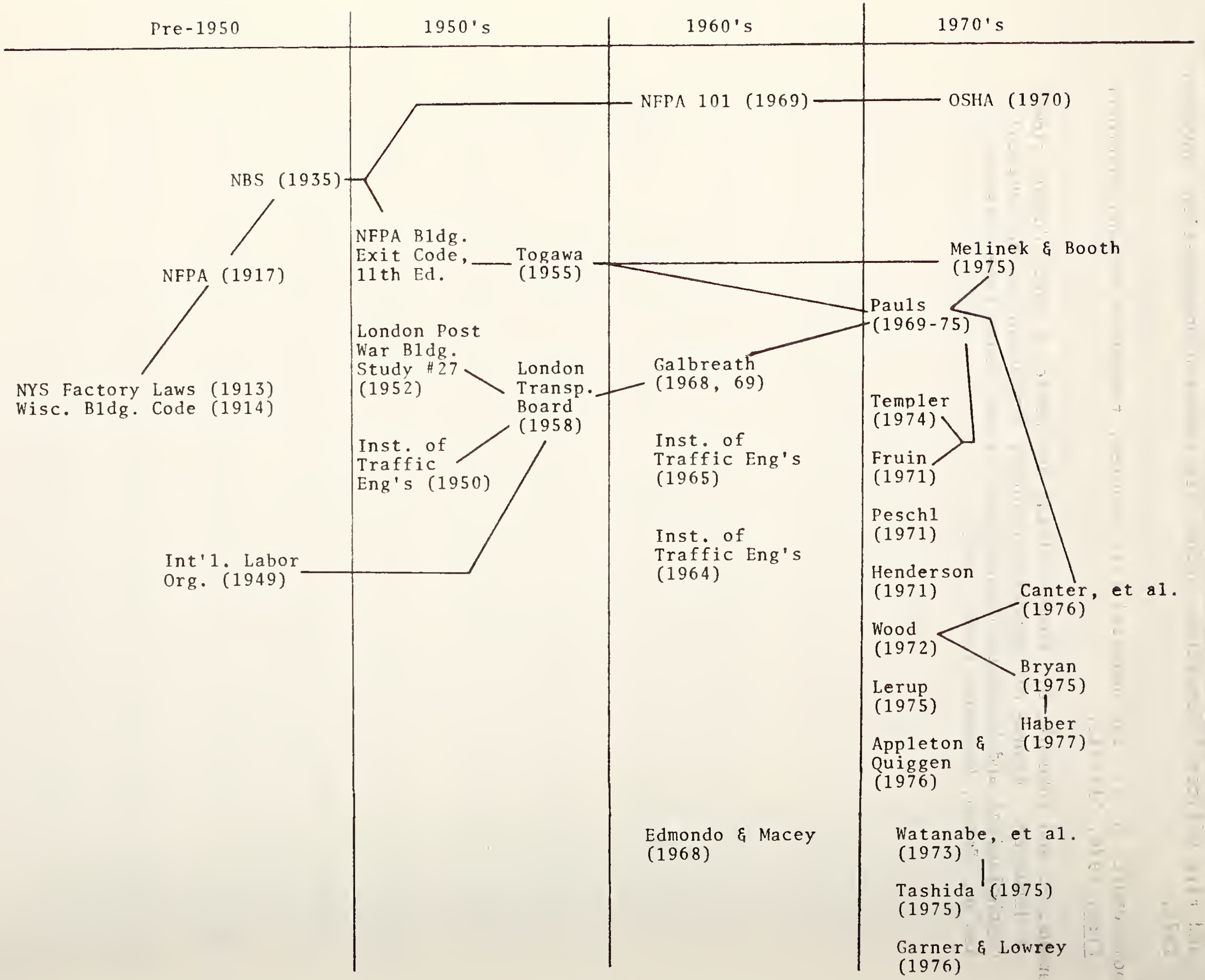

FIG. 1. Historical Development of Emergency Egress Regulation and Research

QUASI-EXPERIMENTAL FIELD STUDIES[1]	NFPA (1917) NBS (1935) Togawa (1955) London Transport (1958) Fruin (1971) Peschl (1971) Henderson (1971) Melinck & Booth (1975) Pauls (1975) Appleton & Quiggen (1976)				
POST-HOC SURVEYS[2]	Wood (1972) Bryan (1976) Haber (1976) Lerup (1976)				
LABORATORY EXPERIMENTS[3]	Watanabe, et al. (1973) Tashida (1975) Edmondo & Macey (1968) Garner & Lowrey (1976)				
	REFERENCES TO THE EMPIRICAL LITERATURE	GENERAL PREMISES	ADVANTAGES OF EMPLOYING THE TECHNIQUE	THREATS TO THE VALIDITY OF FINDINGS	EVALUATION OF THE LITERATURE

NOTES:

(1) Employed primarily in studies of carrying capacity.

(2) Used in investigations of actual fires.

(3) Employed in research on visibility through smoke, emergency lighting and signage. Also, to a very limited degree, used in investigations of carrying capacity.

FIG. 2. Analytical Assessment Matrix.

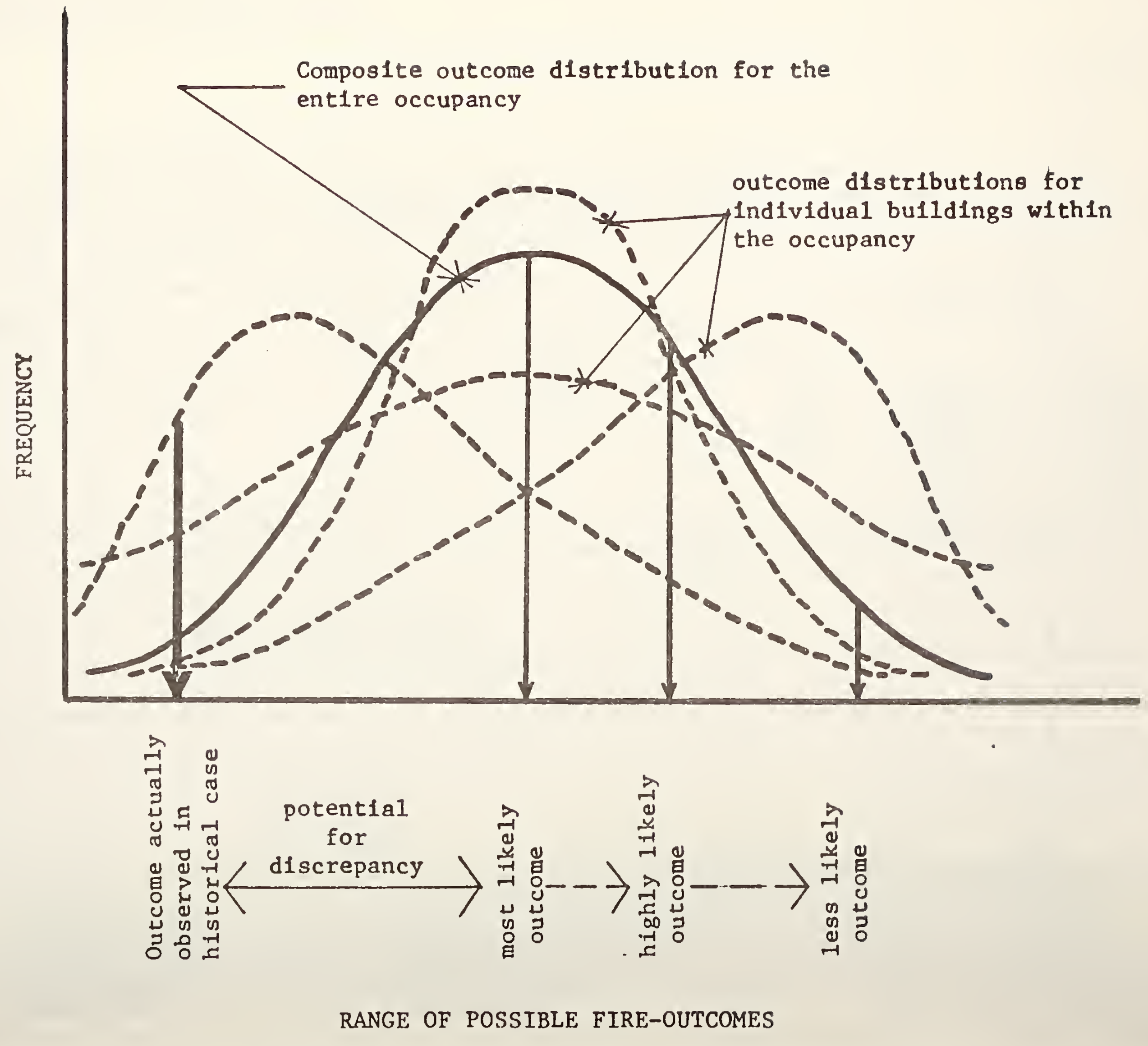

FIG. 3 Theoretical Distribution of Fire-Outcomes, For a Given Occupancy

TABLE 1. Egress Research and the OSHA Regulations: Exemplary Issues

REGULATION		ISSUE	AVAILABLE DATA BASE OF POTENTIAL VALUE	RECOMMENDATIONS FOR FUTURE RESEARCH
1910.36 (b)(2)	"...during the period of time reasonably necessary for escape..."	How is "reasonably necessary" to be defined?	NBS/CFR research on smoke and flame migration, and development of the toxic environment.	
1910.37 (q)(1)	"exits shall be marked with a readily visible sign."	How is "readily visible" to be defined?		Research is required on the optimal location of exit signs and markers, recognizing the special constraints imposed by a smoke-filled environment, as well as the special needs of blind or handicapped occupants.
1910.37 (q)(4)	"every exit sign shall be distinctive in color, and shall provide contrast with... interior finish (etc)."	How are "distinctive" and "contrast" to be defined?	FAA research on sign color and contrast, and sign visibility through smoke.	Research is required to explicate the process of sign and marker perception under stressful and potentially life-threatening conditions.
1910.37 (q)(6)	"every exit sign shall be suitably illuminated by a ...light source giving not less than 5 ft. candles ..."	On what grounds is it accepted that this will save lives?	FAA research on the penetration of illuminated signs through smoke.	Research is required along the lines of the Japanese work on minimum visibility ranges in a smoke-filled environment.
1910.37 (c)(2)	"means of egress shall be measured in units of 22"..."	Research by Pauls has questioned the validity of basing floor load computations on the 22" exit width unit.		Rigorous research is required in order to resolve the question of exit facility utilization, and the concommitant issue of exit design.
1910.36 (b)(7)	"fire alarm facilities shall be provided...to warn occupants of... fire so that they may escape..."	On what grounds can it be accepted that "alarms" will effectively warn and instruct occupants, rather than confuse them?		Research on the effectiveness of alarm signals is required. A useful point of departure would be the "VAS" experience at the Seattle Federal Building.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

An assessment was made of the literature on research related to current emergency egress regulations promulgated by the Occupational Safety and Health Administration (OSHA). The purposes of this assessment were to ascertain the extent to which these regulations were based upon empirical research, and to determine the adequacy of available research findings from which OSHA emergency egress regulations may be developed. Three areas of research on emergency egress were identified: research on (1) the carrying capacity of exitways, (2) signage, lighting, and visibility through smoke, and (3) occupant responses to, and experiences in building fires. Only research on the carrying capacity of exitways appears to have had direct impact on current OSHA regulations, which are based largely on empirical findings reported in 1935. Much of the available data on egress signage, lighting, visibility through smoke, and occupants' responses in real fire situations have appeared since the adoption of standards by OSHA. Consequently, these areas have had minimal impact on OSHA egress regulations. This study provides specific recommendations concerning the technical adequacy and range of applicability of the available empirical literature on emergency egress from buildings. In addition, it provides specific recommendations concerning directions and methodological requirements for future research.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Architectural psychology; architectural research; building codes; building design; building fires; building regulatory standards; emergency egress; exit capacity; fire safety; human performance; regulatory data; occupational safety.

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